6.0 TRAFFIC ENGINEERING AND TRAFFIC OPERATIONS IMPROVEMENTS

The deployment of photo enforcement cameras is one approach available to traffic engineering and law enforcement professionals to enhancing safety at signalized intersections by reducing the number of red light running violations. Data from other photo enforcement programs, as well as data from the City's program as reported in Section 2 of this report, indicates that photo enforcement is effective in reducing red light running violations and accidents caused by motorists running red lights.

However, photo enforcement cameras need to be viewed as one element of the overall traffic operations management infrastructure at the signalized intersections where they are installed. Changes in traffic signal timing, done to enhance traffic operations and safety, may significantly impact the operation of the photo enforcement system. This has occurred in connection with the City's photo enforcement program where changes in the yellow change interval times, implemented by the City's Traffic Engineering Department under that Department's on-going program to review and adjust yellow times, resulted in substantial reductions in the number of red light running violations and questions from ticketed motorists about the program's overall fairness and objectives.

Additionally, changes in traffic signal timing as well as other traffic engineering improvements may also be applied to reduce the incidence of red light running at signalized intersections and, more generally, to enhance public safety at intersections equipped with traffic signals. There are other alternatives to the installation of photo enforcement cameras as a deterrent to red light running at signalized intersections. While photo enforcement cameras will serve to reduce the incidence of red light running violations, comprehensive traffic safety improvement programs are normally built around the three E's of Enforcement, Engineering, and Education and all can be expected to play a role in improving traffic safety. Red light running is clearly one example of risky driving behavior that impacts traffic safety and should be modified but how can this best be achieved? How can intersection safety best be improved?

In this section, the interrelationships between photo enforcement systems and traffic engineering and traffic operations improvements are reviewed. Specifically, the section addresses the following items:

- Yellow change intervals;
- Red clearance intervals; and
- Alternative traffic engineering improvements to reduce red light running.

6.1 YELLOW CHANGE INTERVAL

The purpose of the yellow signal indication is to warn approaching traffic of the imminent change in the assignment of right-of-way. The length of the yellow change interval is determined in such a way that the interval provides enough time for a vehicle to travel at its initial speed through the intersection before the traffic signal turns red or to allow a motorist to stop at a comfortable average deceleration before entering the intersection. Generally, long yellow times are not favored since they may encourage drivers to use it as part of the green time. The Millennium Manual On Uniform Traffic Control Devices (MUTCD) provides that yellow change should be between three and six seconds with the longer intervals being reserved for approaches with higher speeds.

The value chosen should account for driver perception and reaction times, traffic speeds, typical deceleration rates, and grades on the intersection approaches. The City's Traffic Engineering Department employs a method for calculating yellow change intervals that accounts for each of the relevant variables.

It is required that the yellow times at photo-enforced intersections be in compliance with Caltrans Traffic Manual standards for the determination of yellow change intervals. With the release of the Millennium MUTCD, Caltrans standards are the same as those provided by the Millennium MUTCD.

6.1.1 Verification of Yellow Change Intervals

As part of this review, the length of the yellow change intervals at each of the 19 photo-enforced intersections were measured in the field and the field measurements were compared against the both the City's standard and Caltrans Traffic Manual guidelines for yellow change intervals at signalized intersections.

The City of San Diego Traffic Engineering Department provided PBF with the data required to apply the City's standard for yellow times and to verify the actual yellow times. The data presented on Table 6-1 summarizes the data required to calculate yellow times using the City's standard. The data in Table 6-1 includes the yellow times before and after the effective startup date of the photo enforcement system, yellow times taken from the City's traffic signal timing charts, the 85th percentile speeds taken from the most recent speed survey, the posted speed limits, and the range of cycle lengths for the coordinated signal operations. Only one of the 19 photo-enforced intersections, Bernardo Center Drive at Rancho Bernardo, is not included in a coordinated signal system. This intersection operates under fully actuated traffic signal control.

The yellow times at each of the intersections was checked using a stopwatch and collection of 10 samples for each of the red light enforcement movements. Table 6-2 presents the results of the field measurements and provides a comparison of the field measured yellow times to yellow times shown on the City's signal timing charts. A review of Table 6-2 shows that the yellow times observed in the field are generally the same the times shown on the City's timing sheets.

Also shown on Table 6-2 is the yellow time based on the City's adopted guideline for the determination of yellow times. The City's guideline is taken from Determining Vehicle Signal Change and Clearance Intervals prepared by the ITE Technical Council Task Force 4TF-1, dated August 1994. The formula used by the City is as follows:

$$y = t + \frac{V}{2a + 2Gg}$$

where: y = length of the yellow time change interval, to the nearest 0.1 second;

t = driver perception/ reaction time, generally assumed as 1.0 second;

V = speed of approaching vehicle, in ft/sec (m/sec), input as the higher of the 85th percentile speed or posted speed limit;

a = average deceleration, assumed for 10 ft/sec^2 (3.0 m/sec^2) to 15 ft/sec^2 (4.5 m/sec^2) (City uses 10 ft/sec^2);

Table 6-1
SUMMARY OF SIGNAL TIMING, SPEED AND SIGNAL CYCLES AT PHOTO-ENFORCED INTERSECTIONS

Code	Location	Effective Turn On Date	Yellow Time Prior To Turn On Date	Yellow Time After Turn On Date	Traffic Speed - 85th Percentile	Posted Speed Limit	Signal Cycle Length
1404	WB El Cajon Boulevard at 43rd Street	07/30/98	3.50	3.70	34	35	120 to 140
1444	WB Harbor Drive at 32nd Street	12/07/98	4.50	4.50	50	40	110 to 120
1454	WB Garnet Avenue At Ingraham Avenue	12/07/98	3.00	3.20	27	30	100 to 120
1484	WB Imperial Avenue at Euclid Avenue	04/02/99	4.10	4.10	42	35	110 to 120
1504	WB F Street at 16th Street	04/02/99	3.30	4.90	N/A	25	70
1523	EB A Street at 10th Avenue	02/24/00	4.90	3.30	N/A	25	70
1534	WB Miramar Road at Camino Ruiz	02/24/00	4.80	4.80	48	45	96 to 130
1542	SB Mission Blvd. at Garnet Avenue	05/19/00	3.00	3.70	37	35	100 to 120
1551	SB Black Mountain Road at Gemini Avenue	04/20/00	3.80	3.80	43	35	120 to 160
1553	EB Mira Mesa Boulevard at Scranton Road	04/20/00	3.90	4.30	40	45	180
1414	NB Bernardo Center Drive to WB Rancho Bernardo Road	07/30/98	3.00	3.00	39	35	Fully Actuated
1422	WB Aero Drive to SB Murphy Canyon Road	07/30/98	3.00	3.00	49	45	100 to 120
1462	SB College Avenue to Montezuma Road	12/07/98	3.00	3.00	38	35	104 to 110
1474	WB La Jolla Village Drive to Towne Center Drive	12/07/98	3.00	3.00	50	45	138 to 150
1492	SB Black Mountain Road. to Mira Mesa Boulevard	04/02/99	3.00	3.00	43	35	120 to 160
1513	EB Garnet Avenue to NB Mission Bay Drive	04/02/99	3.00	3.00	31	35	150 to 200
1533	North SB Harbor Drive to EB Grape Street	10/07/99	3.00	3.00	43	35	80 to 105
1541	NB Mission Bay Drive to WB Grand Avenue	05/19/00	3.00	4.70	50	45	75 to 100
1543	EB Carmel Mountain Road to NB Rancho Carmel Drive	02/24/00	3.00	3.00	38	45	120 to125

N/A = Not Available (Business District)

Table 6-2
SUMMARY OF YELLOW CHANGE INTERVALS

Code	Location	Field Survey Dates	Average Yellow Time (a)	Yellow Time After Turn On Date	Caltrans Traffic Manual	Yellow Time Equals Or Exceeds Caltrans Standard	City Standard Yellow Time	Yellow Time Equals Or Exceeds City Standard
1404	WB El Cajon Boulevard at 43rd Street	09/27/01	3.75	3.7	3.5	YES	3.6	YES
1444	WB Harbor Drive at 32nd Street	10/01/01	4.52	4.5	4.7	NO	4.7	NO
1454	WB Garnet Avenue at Ingraham Avenue	09/26/01	3.25	3.2	3.1	YES	3.2	YES
1484	WB Imperial Avenue at Euclid Avenue	10/01/01	4.07	4.1	4.0	YES	4.1	YES
1504	WB F Street at 16th Street	09/26/01	4.91	4.9	3.1 (b)	YES	3.1	YES
1523	EB A Street at 10th Avenue	10/01/01	3.33	3.3	3.1 (b)	YES	3.0	YES
1534	WB Miramar Road at Camino Ruiz	09/25/01	4.79	4.8	4.5	YES	4.5	YES
1542	SB Mission Boulevard at Garnet Avenue	09/26/01	3.63	3.7	3.7	YES	3.7	YES
1551	SB Black Mountain Road at Gemini Avenue	09/25/01	3.69	3.8	4.1	NO	4.2	NO
1553	EB Mira Mesa Boulevard at Scranton Road	09/25/01	4.12	4.3	3.9	YES	4.3	YES
1414	NB Bernardo Center Drive to WB Rancho Bernardo Road	09/25/01	3.01	3.0	3.1 (c)	NO	3.0	YES
1422	WB Aero Drive to SB Murphy Canyon Road	09/25/01	3.08	3.0	3.1 (c)	NO	3.0	YES
1462	SB College Avenue to Montezuma Road	09/26/01	3.03	3.0	3.1 (c)	NO	3.0	YES
1474	WB La Jolla Village Drive at Towne Center Dr.	10/03/01	3.01	3.0	3.1 (c)	NO	3.0	YES
1492	SB Black Mountain Road to Mira Mesa Blvd.	09/26/01	3.07	3.0	3.1 (c)	NO	3.0	YES
1513	EB Garnet Avenue to NB Mission Bay Drive	09/25/01	3.07	3.0	3.1 (c)	NO	3.0	YES
1533	North SB Harbor Drive to EB Grape Street	10/01/01	3.03	3.0	3.1 (c)	NO	3.0	YES
1541	NB Mission Bay Drive to WB Grand Avenue	09/25/01	4.67	4.7	3.1 (c)	YES	3.0	YES
1543	EB Carmel Mountain Road to NB Rancho Carmel Drive	09/25/01	3.20	3.0	3.1 (c)	NO	3.0	YES

NOTE: (a) Average yellow time represents the average of the field measurement of ten (10) yellow times collected in the field using a digital stopwatch.
(b) Based on posted speed limit, not on 85th percentile speed.
(c) Based on estimated 25 miles per hour for protected left turn movements.

g = acceleration due to gravity, 32 ft/sec^2 (9.81 m/sec^2); and

G = grade of approach, in percent divided by 100 (downhill is negative grade).

As shown in Table 6-2, it was determined that the actual yellow times were equal to or higher than the actual yellow times at all but two intersections where photo enforcement cameras are installed. The intersections where the yellow times were lower than the City's guideline were at Harbor Drive and 32nd Street (4.5 seconds actual versus 4.7 seconds per City's guideline) and Black Mountain Road and Gemini Avenue (3.7 seconds actual versus 4.2 seconds per City's guideline).

It was also observed that the measured time at the intersection of Mira Mesa Boulevard and Scranton Road was slightly lower than the yellow time shown on the City's signal timing sheets but this difference is not significant.

6.1.2 Longer Yellow Change Intervals

Findings from the studies conducted by the Insurance Institute For Highway Safety indicate that increasing the length of the yellow change interval significantly decreased the frequency of red light running, at least in the short term after the length of the yellow change interval was increased. These and other research studies have reported between 70 and 82 percent of all red light violations happen in less than 1.5 seconds after the yellow signal indication. Longer yellow change intervals serve to reduce red light violations and the potential that they introduce for collisions.

The research studies also found that intentional violators are not deterred by the length of the yellow change interval and red light running is still frequent at intersections, where the yellow change interval is as much as 40 percent greater than the intervals recommended by the ITE guidelines. Intentional violators use the yellow change interval intentionally and recurrently as a part of the green interval. On the other hand, longer yellow change intervals do serve to reduce the number of violations by unintentional violators. Although compliance with the longer yellow change intervals may eventually deteriorate, it is believed that the reductions observed for unintentional violators are sustained over extended time periods.

The yellow change intervals were modified at six photo-enforced intersections after the startup of the City's photo enforcement program. These modifications were done as part of the City Traffic Engineering Department's on-going review and adjustment of the yellow change intervals throughout the City and were not related to the photo enforcement program.

A comparison of the numbers of red light running violations before and after the modifications in the yellow change intervals at the five photo enforced intersections confirms the findings of the Insurance Institute's research studies. The before and after violations data is shown in Figure 6-1.

The most significant change in the number of violations occurred at the intersection of Mission Bay Drive and Grand (1541) where the yellow change interval was extended from 3.1 seconds to 4.7 seconds. This change resulted in an 88-percent decrease in the number of violations. At the five other intersections, the number of violations dropped significantly in response to longer yellow times.

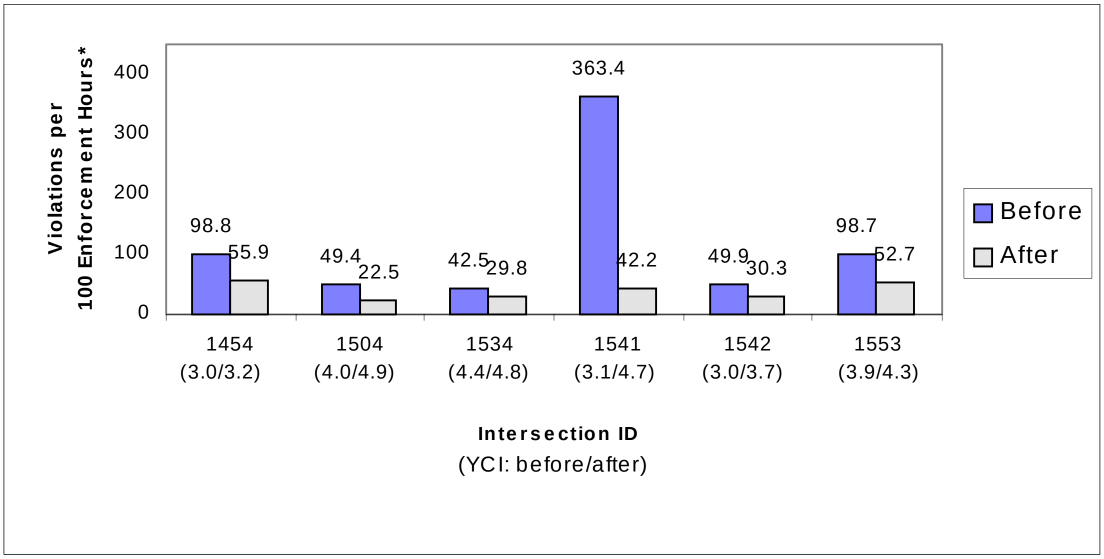

Figure 6-1
VIOLATIONS DATA FOR SELECTED PHOTO ENFORCED INTERSECTIONS BEFORE AND AFTER YELLOW CHANGE INTERVAL MODIFICATIONS

6.2 RED CLEARANCE INTERVAL

All traffic signals in the City employ a one-second red clearance interval at the end of each phase, before green signal indications are given to the opposing traffic phase. For purposes of photographing violators and issuing citations, the one-second red clearance interval is considered as a red signal.

The red clearance interval is not intended to reduce the incidence of red light running; it is a safety measure that separates the last red light runner from the first green light runner for one or two critical seconds, which is sufficient to prevent a collision in most cases. Studies conducted by the Insurance Institute For Highway Safety found that the use of the red clearance interval appeared to be effective in reducing the number of right angle collisions, also noting that a large proportion of red light runners tend to be shortly after the red light is displayed.

The Millennium MUTCD guidance is that the red clearance interval should not exceed six seconds in length.

6.3 RED LIGHT RUNNING ALTERNATIVE MEASURES

One of the recent studies of red light running by the Insurance Institute For Highway Safety determined that red light running tends to be recurrent among certain drivers. The study found that the typical red light runner was younger, less likely to wear safety belts, have a poorer driving record, and drove smaller and older vehicles than drivers who stopped for red lights. They were more than three times as likely to have multiple speed convictions on their driving records. The study concluded that red light violators are a "higher risk group" that merits enforcement resources not only because of the violation itself and its danger, but also because of their higher risk characteristics in general.

The existence of this intentional red light running group of drivers indicates that engineering countermeasures would have limited ability to change this behavior. For this group, enforcement and education need to be pursued with determination. Unintentional red light runners may however be assisted by traffic engineering or operational improvements to intersections. These should also be identified, prioritized, and implemented as appropriate.

Researchers at the Texas Transportation Institute classified red light runners as shown in Table 6-1. This table also summarizes the expected effectiveness of countermeasure alternatives for the types of red light runners and the conditions contributing to red light running.

Table 6-3
RED LIGHT RUNNING DRIVER TYPES AND POSSIBLE COUNTERMEASURES

<table>
<tr><th colspan="2" rowspan="2">Red Light Running Driver Type</th><th rowspan="2">Possible Scenario</th><th colspan="2">Type Of Countermeasure</th></tr>
<tr><th>Engineering</th><th>Enforcement</th></tr>
<tr><td colspan="2">Intentional</td><td>Congested, Cycle Overflow, Habitual</td><td>Less Effective</td><td>Most Effective</td></tr>
<tr><td rowspan="2">Unintentional</td><td>Type A</td><td>Unable To Stop Due To Speed Or Other Factors</td><td rowspan="2">Most Effective</td><td rowspan="2">Less Effective</td></tr>
<tr><td>Type B</td><td>Inattentive</td></tr>
</table>

Source: Texas Transportation Institute

The literature suggests a broad consensus that automated enforcement is a practical means of reducing red light running and increasing safety at intersections. However, it should not be introduced in isolation from a package of measures all aimed at improving intersection safety. Additional countermeasures that may be considered as an alternative to or in addition to the use of photo enforcement cameras are the following.

6.3.1 Enhanced Advance Warning Signs

Caltrans standard photo enforcement signs are located at each of the photo-enforced intersections. However, warning signs installed in advance of the intersections on the photo-enforced approaches can also be used to alert motorists and this approach is more commonly used by cities in the State of California. The sign at the intersection serves as an additional reinforcement that photo enforcement cameras are being used. Advance warning is of importance to both intentional and unintentional violators and should contribute to a reduction in the number of violations by both groups as well as providing additional public education and fair warning that photo enforcement cameras are being used.

6.3.2 Advanced Flashing Yellow Light Installation.

Where motorists unintentionally enter an intersection on a yellow or red signal indication, some of the factors that may contribute to this action may include the following:

- Weather conditions;
- Pavement conditions;
- Inattention or distractions;
- Vehicle speed;

- Vehicle distance from intersection; and
- Vehicle type.

The use of advanced yellow flashing lights may reduce the number of red light violations at an intersection. These traffic control devices are situated well in advance of an intersection and only flash at approaching motorists when the signal indication is about to turn yellow. This operation is different than the typical flashing yellow light in advance of an intersection that simply warns of the existence of the signalized intersection or a potentially hazardous condition.

Advanced warning flashers and their effect on red-light-running violations was studied in Bloomington, Minnesota. The intersection of U.S. Highway 169 and Pioneer Trail was chosen as a case study intersection based on its recent accident history, perceived and observed occurrences of red light running, traffic speeds, traffic mixture, and ease of equipment installation. The advanced warning flashers were used for approximately three months. Red light running violations data was collected before, during, and after the use of warning flashers. It was determined that the installation of the advanced yellow flashing lights reduced red light running violations at the intersection by 29 percent overall and, for trucks, by an impressive 63 percent.

6.3.3 In Pavement Warning Lights

The City of Anaheim recently completed an evaluation of the use of in-pavement warning lights at a signalized intersection used by the rubber-tired tram vehicles that transport visitors to Disneyland between the parking areas and the park facilities. The evaluation was done under the oversight of the California Traffic Control Devices Committee. For the evaluation project, in-pavement warning lights were installed in advance of the stop line on both approaches to the intersection where the tram vehicles crossed. Before and after data was collected regarding red light running violations and a significant reduction in the number of red light running violations was recorded.

The Millennium MUTCD limits the application of in-pavement warning lights to pedestrian crosswalks at intersections that are not controlled by traffic signals or other traffic control devices. Their use as a possible deterrent to red light running at signalized intersections is not approved except under experimental conditions as done in the City of Anaheim.

6.3.4 Cross Street Green Delay Time

Photo enforcement systems deployed in the cities of Irvine and Culver City provide for a one-second delay or hold on the intersecting street green time when a red light running violation is detected. While this feature does not serve to reduce the number of red light running violations, it does provide an effective means to reducing the likelihood that the red light running violation will result in a collision.

6.3.5 Coordinated Traffic Signal Operations

A coordinated traffic signal operation where motorists are able to move smoothly in platoons from intersection to intersection reduces the risk of a red light running violations and collisions resulting from red light running violations. The traffic signals at 18 of the City's photo-enforced intersections are coordinated with the traffic signals at adjacent intersections.

Longer signal cycle times may also be a contributing factor to red light running as motorists become impatient or elect to not wait for the next cycle to enter an intersection. However, longer cycle times are necessary to provide the necessary capacity to accommodate the traffic volumes that use the City's arterial street network, especially during the peak periods.

6.3.6 Recap

Table 6-2 below summarizes the red light running countermeasures and the manner in which they can be expected to promote traffic safety by influencing different types of behavior. As can be seen, unintentional red light running is more susceptible to traffic engineering and operation measures while photo enforcement is considered to be the most effective mechanism for reducing red light running violations by intentional violators.

Table 6-4
SUMMARY OF SELECTED ENGINEERING COUNTERMEASURES

Countermeasure	Reduce Intentional Violations	Reduce Unintentional Violations	Reduce Right-Angle Collisions
Longer Yellow Change Interval	Less Effective	Most Effective	Effective
Red Clearance Interval	No Difference	No Difference	Effective
Enhanced Advance Warning Signs	Less Effective	Probably Effective	Probably Effective
Advance Warning Flashing Lights	Less Effective	Probably Effective	Probably Effective
In-Pavement Warning Lights	Less Effective	May Be Effective	May Be Effective
Cross Street Green Delay Time	No Difference	No Difference	No Difference
Coordinated Traffic Signal Operation	Effective	Effective	Effective
Red Light Camera Enforcement	Most Effective	Most Effective	Most Effective

6.4 TOP PRIORITY INTERSECTIONS FOR TRAFFIC SAFETY IMPROVEMENTS

The City Traffic Engineering Department reviews accident data for the City's 1,500 signalized intersections and, on an annual basis, prepares a list that identifies the City's "top priority" locations where traffic safety improvements are needed. The locations are selected on the basis of accident data and community inputs regarding potentially hazardous locations. A diagnostic review is conducted for each of these "top priority" locations and appropriate improvements are recommended.

The types of improvements may include changes in traffic signal timing, the installation of additional traffic control devices including traffic signals at intersections that are not signalized, signing and striping improvements, pedestrian-oriented treatments, and street modifications or widening.

6.5 FINDINGS AND RECOMMENDATIONS

- The actual yellow change intervals at 17 of the photo-enforced intersections are equal to or higher than yellow times calculated using the City's guidelines. The intersections where the yellow times were lower than the City's guideline were at Harbor Drive and

32nd Street (4.5 seconds actual versus 4.7 seconds per City's guideline) and Black Mountain Road and Gemini Avenue (3.7 seconds actual versus 4.2 seconds per City's guideline).

Speed surveys should be done for the approaches at the two intersections where the yellow times did not meet the City's guidelines in order to re-calculate the yellow times for these intersections. The yellow times should be adjusted accordingly when the yellow times have been re-calculated.

- SB 667 requires that the yellow change intervals be based on the Caltrans Traffic Manual. The yellow change intervals at 10 of the 19 photo-enforced intersections are shorter than the yellow times specified by the Caltrans Traffic Manual. Eight of the yellow change intervals that are not in compliance are for left turns where the Caltrans Traffic Manual specifies a minimum yellow time of 3.1 seconds, as opposed to 3.0 seconds per the City guidelines.

  Before the photo enforcement systems is re-started, it will be necessary to adjust the yellow change intervals to be in compliance with the Caltrans Traffic Manual, including any changes being implemented or considered for the Caltrans Traffic Manual that may be required for compliance with the Millennium MUTCD.

- It is a key recommendation of this review that the City's Police Department work more closely with the City's Traffic Engineering Department to develop a comprehensive methodology for the deployment of photo enforcement cameras in the City, building upon the Traffic Engineering Department's on-going traffic safety improvement program and resulting in the future deployment of photo enforcement cameras within the context of an overall traffic safety improvement program; to ensure that the yellow change intervals at photo-enforced intersections are adjusted in accordance with the City's guidelines; to coordinate photo enforcement system installations so that vehicle detection is provided for both photo enforcement and traffic signal control applications without one adversely impacting the other; and to reinforce the mutual interests and capabilities of the City's law enforcement and traffic engineering professionals to develop an overall traffic safety improvement program for the City that is a model for other cities and agencies throughout California.